[0171] As seen from the conduction band diagram in FIG. 11B, electrons can be injected from the N+ emitter as non-hot electrons having an energy E less than that of the conduction band minimum of the graphene material base layer. The non-hot electrons are transported through the base by diffusive transport, ballistic transport, and/or coherent transport and enter optionally as hot or ballistic electrons into the collector.

Advantages and New Features:

[0172] One of the primary advantages of graphene is that it has extremely high electric conductivity for extremely thin graphene material base layer. One of the critical parameters for transistors is the base resistance and thus, graphene can have a low base resistance even for very thin graphene material base layers. A low base resistance is important to achieve a high maximum frequency of oscillation, fmax. The high electrical conductivity of graphene allows the use of thin graphene material base layer which reduces the transit time of electrons through the base layer and also reduces the scattering energy loss of hot electrons in transiting the thin graphene base material. Many scientists believe that graphene has the potential to have the highest conductivity of any material and can have a higher conductivity of than silver for the same thickness. Experimental results indicate that the resistivity of a single sheet of graphene approximately 3 angstrom thick grown on the silicon face of SiC has a sheet resistance on the order of 750 ohm/square to 1000 ohms/square. Experimental results also indicate that a graphene sheet grown on the surface of copper can have a sheet resistance of approximately 1200 to 1500 ohms/square. The sheet resistance of graphene material having a few sheets of graphene can be less than 100 ohms/square. The thickness of a few sheets of graphene can be less than 1 nm. In addition, the high velocity of electrons in the graphene material can lower the base transit time. Thus, the semiconductor device with graphene material base layer can have high fT and high fmax.

[0173] The use of graphene for base layer of a transistor can allow wide bandgap materials such as AlGaN, GaN, InAlN, and SiC to be used as the collector layer material of the transistors. AlGaN, GaN, InAlN and SiC have extremely high Johnson figure of merit and thus the graphene base transistor can allow high power, high frequency operation.

[0174] The use of graphene for base layer of a transistor can allow wide bandgap materials such as AlGaN, GaN, InAlN, and SiC to be used as the collector material of the transistors. Because of the wide bandgap nature of AlGaN, GaN, InAlN and GaN, the graphene base transistor can allow high temperature operation.

[0175] The enhanced lateral thermal conductivity of graphene can spread the thermal load to a larger area and thus reduce the thermal resistance.

[0176] The use of graphene for the base layer also can lower the transistor turn-on voltage thereby reducing power dissipation within the device.

[0177] Although particular embodiments, aspects, and features have been described and illustrated, one skilled in the art would readily appreciate that the invention described herein is not limited to only those embodiments, aspects, and features but also contemplates any and all modifications within the spirit and scope of the underlying invention described and claimed herein, and such combinations and embodiments are within the scope of the present disclosure.

What is claimed is:

1. A transistor device comprising:

a graphene material base layer comprising at least one sheet of graphene;

a emitter adjacent to a first side of the graphene material base layer and forming an emitter/base interface therewith;

a collector adjacent to a second side of graphene material base layer opposite the first side and forming a collector/base interface therewith; and

a plurality of electrodes, each of the plurality of electrodes being connected to and forming a separate electrical connection with one of the emitter, collector, and base.

2. The transistor device according to claim **1**, wherein a portion of the emitter has a conduction band minimum at a higher energy than a conduction band minimum of the graphene material base layer and is configured to inject electrons into the graphene material base layer having an energy E greater than a Fermi energy E_F of the graphene material base layer to produce hot electrons in the graphene material base layer.

3. The transistor device according to claim **1**, wherein the emitter is configured to inject electrons into the graphene material base layer having an energy E approximately equal to a Fermi energy E_F of the graphene material base layer to produce non-hot electrons in the graphene material base layer.

4. The transistor device according to claim **1**, wherein the emitter comprises an N-type semiconductor material.

5. The transistor device according to claim **1**, wherein the electrodes form ohmic electrical connection to the emitter, collector, and base.

6. The transistor device according to claim **1**, wherein the electrodes connected to the emitter and to the base layer form ohmic electrical connections and the electrode connected to the collector forms a Schottky connection.

7. The transistor device according to claim **1**, wherein the emitter comprises one or more of ZnO, BN, InGaN, InAsP, InP, InGaAs, InAlAs, InGaSb, Diamond, GaN, GaAs, Silicon, 4H—SiC, GaSb, Germanium, AlP, ZnS, GaP, AlSb, AlAs, InGaN, and MN emitter material layers.

8. The transistor device according to claim **7**, where at least one emitter material layer includes a plurality of sublayers each having a selected doping concentration, wherein a first one of the plurality of sublayers is in contact with the electrode and has an N-type dopant concentration sufficient to make ohmic contact to the electrode, and wherein a second one of the plurality of sublayers has an N-type dopant concentration sufficient to provide a high density of carriers for injection into the graphene base layer.

9. The transistor device according to claim **7**, where in the emitter material layer is a single-crystal, polycrystalline, highly oriented, nanocrystalline, amorphous material layer.

10. The transistor device according to claim **7**, wherein one or more of the emitter material layer is P-type doped, has a P-type delta layer, or has graded P-type doping to implement a thermionic emission injection structure.

11. The transistor device according to claim **7**, where in the emitter material layer is grown selectively.

12. The transistor device according to claim **1**, wherein the base comprises a quantum well having energy levels and the carriers transport through the base layer by resonant tunneling.